



CDF Searches for **New Physics** at High Diphoton and Dilepton Masses



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- Motivation - Alternatives to SUSY
- Introduction to the Tevatron and CDF
- Dilepton (ee , $\mu\mu^*$) and $\gamma\gamma$ Event Selection
- Comparison of Background Expectation to Data
- Spin Dependent Acceptances
- Preliminary Results
- Summary and Conclusions

* $\tau\tau$ searches presented by A. Anastassov

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Alternatives to SUSY

to Solving the Hierarchy Problem

($M_{EW} \ll M_{\text{Planck}}$)

Extra dimensional (ED) solutions



to Solving the Hierarchy Problem

($M_{EW} \ll M_{\text{Planck}}$)

Extra dimensional (ED) solutions

ADD

Taking compact space to be very large



Gravity freely propagates in the many large extra dimensions ($n=2-7$)

$$M_P^{-2} = V_n M_{Pl}^{(4+n)^{(2+n)}}$$

To solve hierarchy: $M_{Pl(4+n)} \sim 1 \text{ TeV}$

hep-ph 9803315

RS

Curvature of the extra dimension

1 highly curved extra dimension
Gravity localised in the ED
Scale of physical phenomena on the TeV-brane is specified by the exponential warp factor:

$$\Lambda_\pi = \bar{M}_{Pl} e^{-kR_c\pi}$$

$$\Lambda_\pi \sim \text{TeV if } kR_c \sim 11-12.$$

hep-ph 9905221

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Search for ED?

- Deviations in cross sections (σ) and angular distributions from SM processes caused by graviton exchange
- Resonance in RS model and broad change in σ in ADD model

Dilepton Channel	Diphoton Channel

- ✓ Clean experimental signature
- ✓ Low backgrounds
- ✓ **Also search for other physics models**

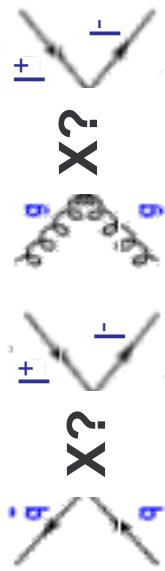


Other New Physics Searches in Dilepton Channels



Also set limits on new physics

- Z' (E6 and Little Higgs) (Spin-1)
- RPV sneutrinos (Spin 0)



Search Strategy

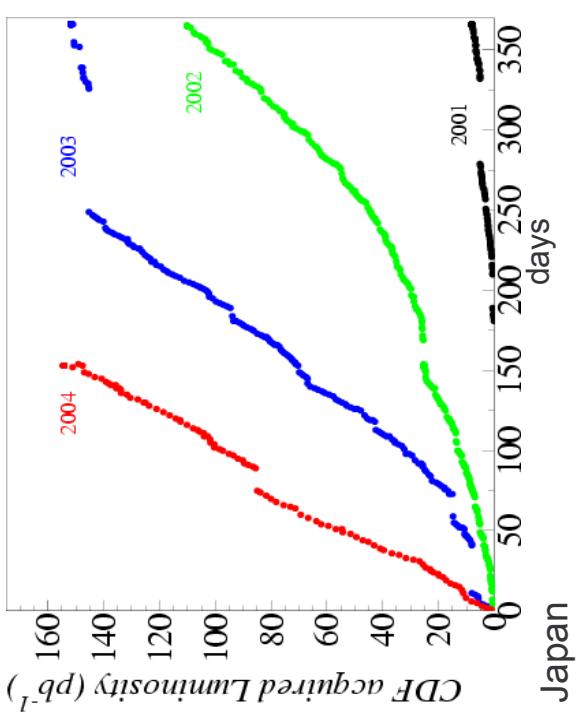
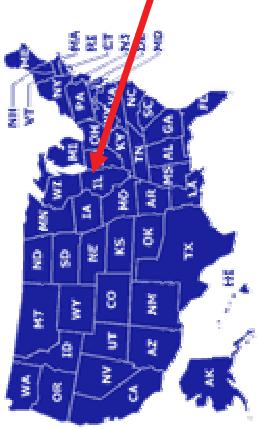
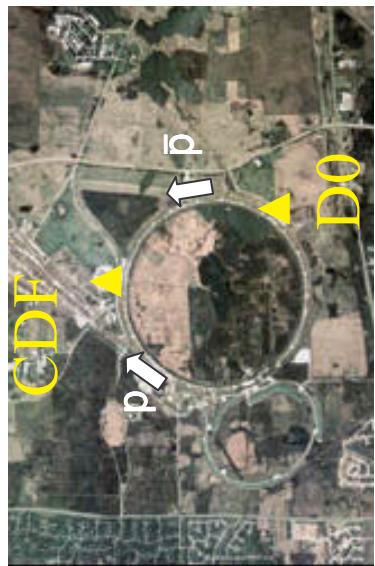
- Perform general searches comparing data to expectation
- Determine spin dependent acceptance and $\sigma \cdot BR$
- Interpret data according to many new models!



CDF @ Tevatron $p\bar{p}$ Collider



Highest energy collider operating in the world!



Run I (1992-1996)
 $\sqrt{s} \approx 1.8 \text{ TeV}, 110/\text{pb}$
Run II (2001-2009)
 $\sqrt{s} \approx 1.96 \text{ TeV}$
Physics Analyses use $\sim 200/\text{pb}$
collected between 03/02 and 09/03

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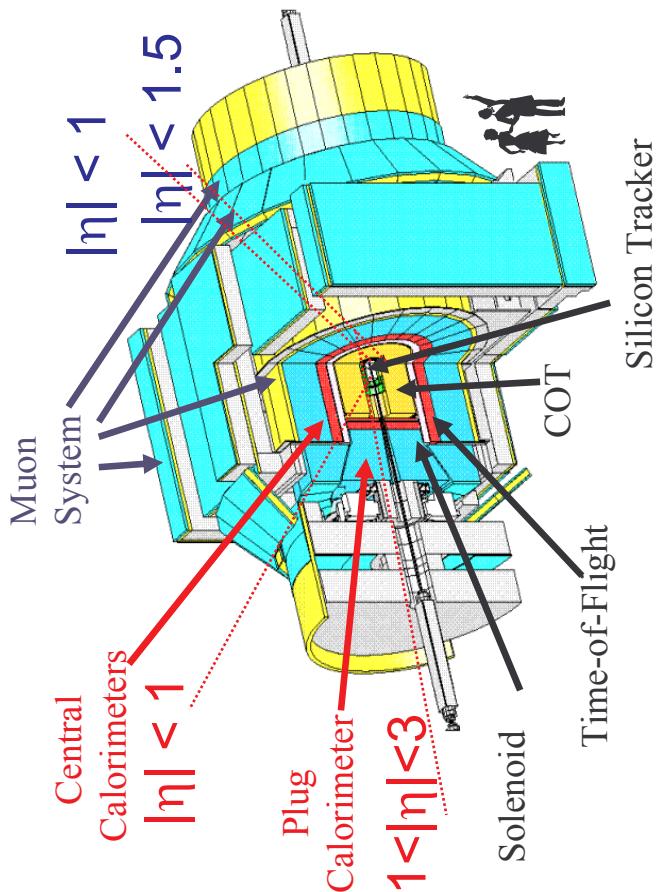
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Search Selection

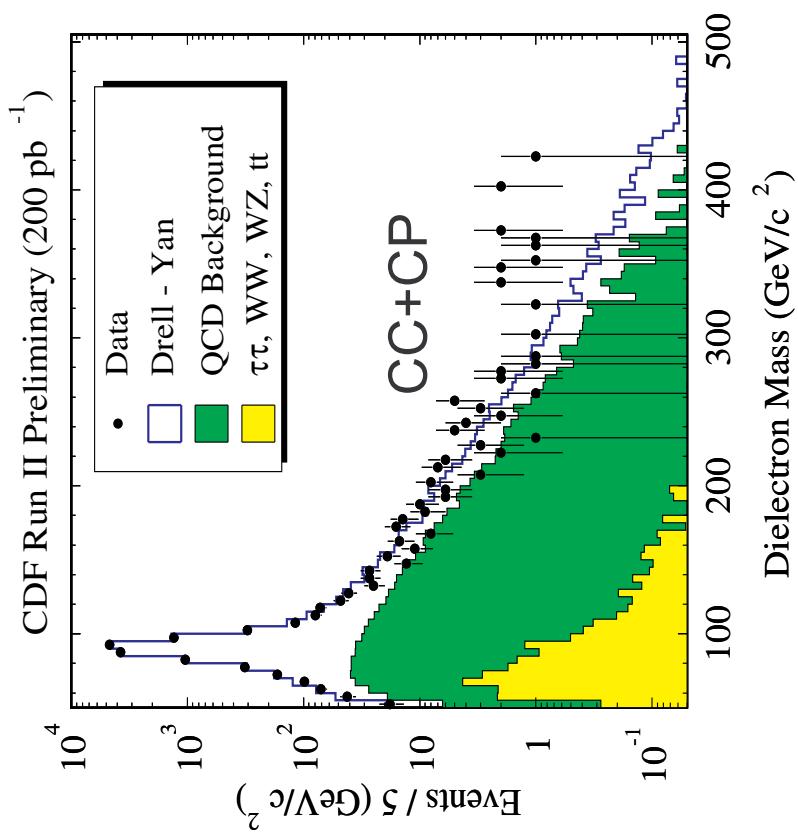


$\mu\mu$	2 isolated μ $P_T > 20 \text{ GeV}$ $ \eta_{\mu 1} < 1, \eta_{\mu 2} < 1.5$ Cosmic ray rejection cuts
ee	2 two isolated e , $E_T > 25 \text{ GeV}$ 2 central e (CC) or 1 central and 1 forward e (CP)
$\gamma\gamma$	2 isolated γ $E_T > 15 \text{ GeV}$ 2 central γ (CC)





High Mass Dielectrons



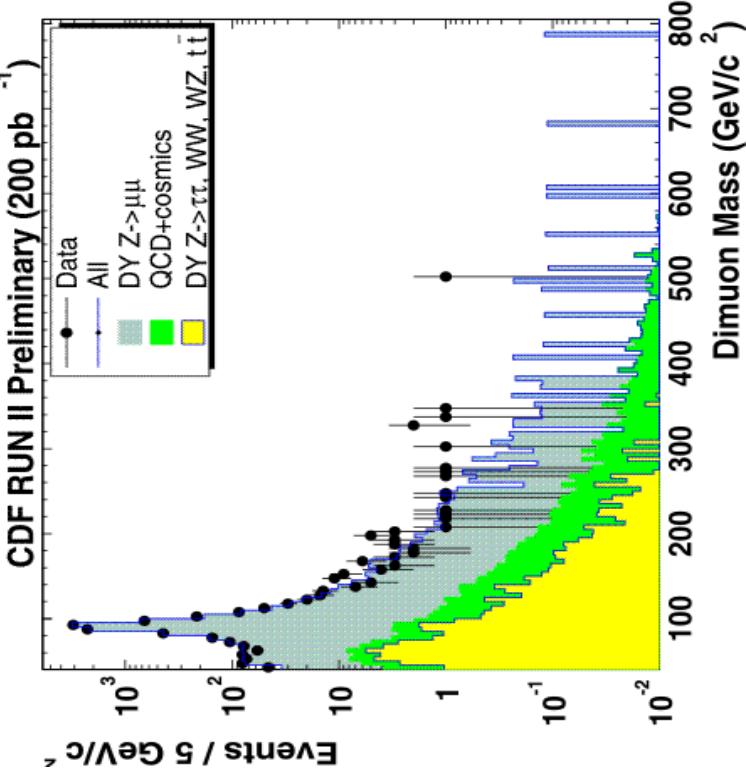
Mass (GeV/c ²)	N _{exp}	N _{obs}
200	70.5	71
250	26.7	30
300	11.1	14
350	4.6	9
400	2.0	2
450	0.9	0

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High Mass Dimuons



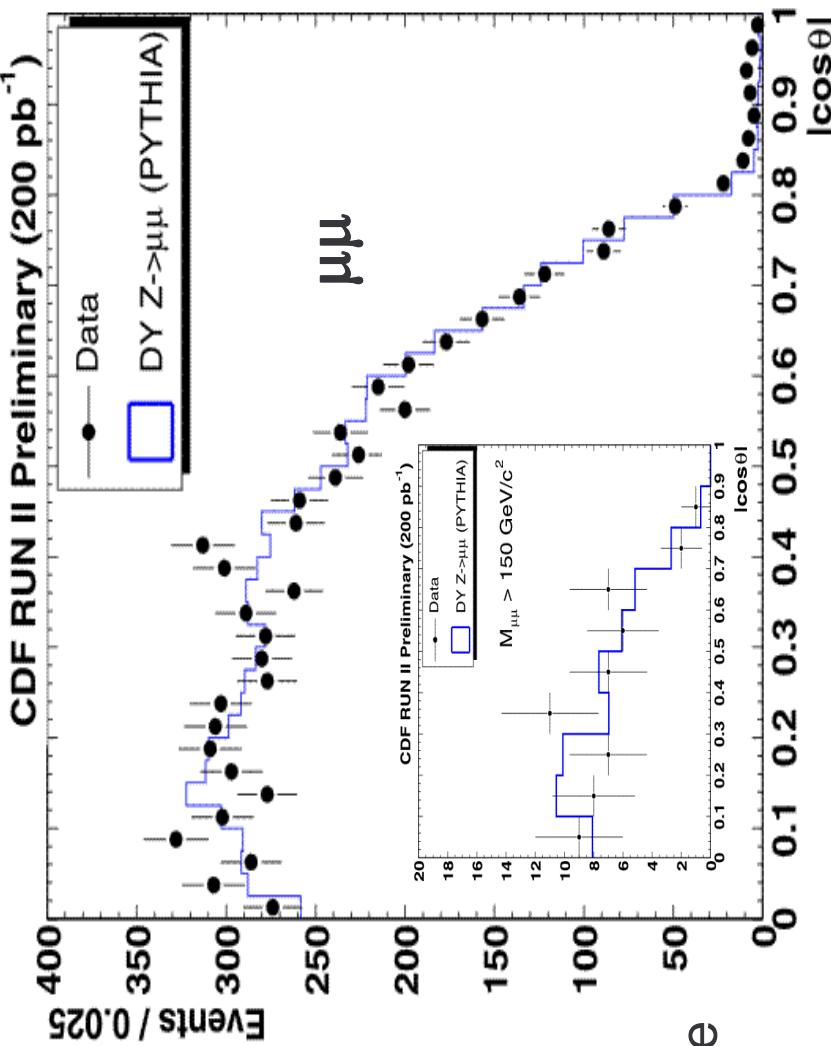
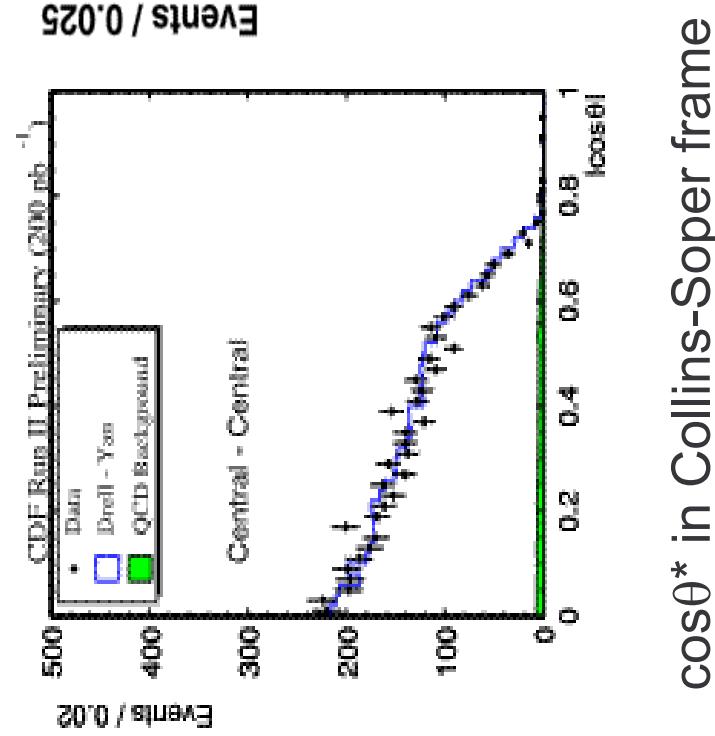
Mass (GeV/c ²)	N _{exp}	N _{obs}
150	55.25 ± 2.50	58
200	20.88 ± 0.97	18
250	9.44 ± 0.49	9
300	5.22 ± 0.32	6
350	3.23 ± 0.24	1
400	2.28 ± 0.19	1
450	1.79 ± 0.16	1
500	1.24 ± 0.13	1
550	1.03 ± 0.11	0

Total of ~ 7500 dimuon candidates in 200 pb⁻¹ data

High mass dilepton spectra is consistent with background prediction



Dilepton Angular Distributions

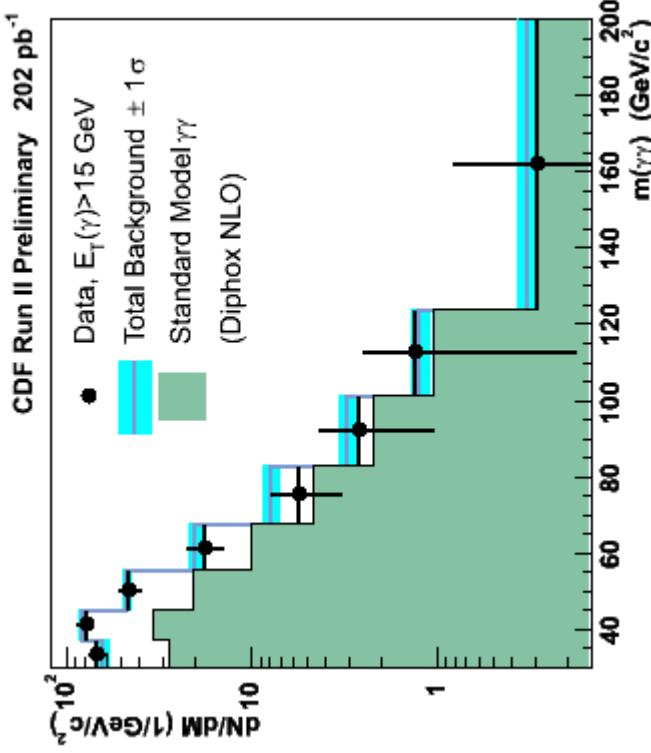


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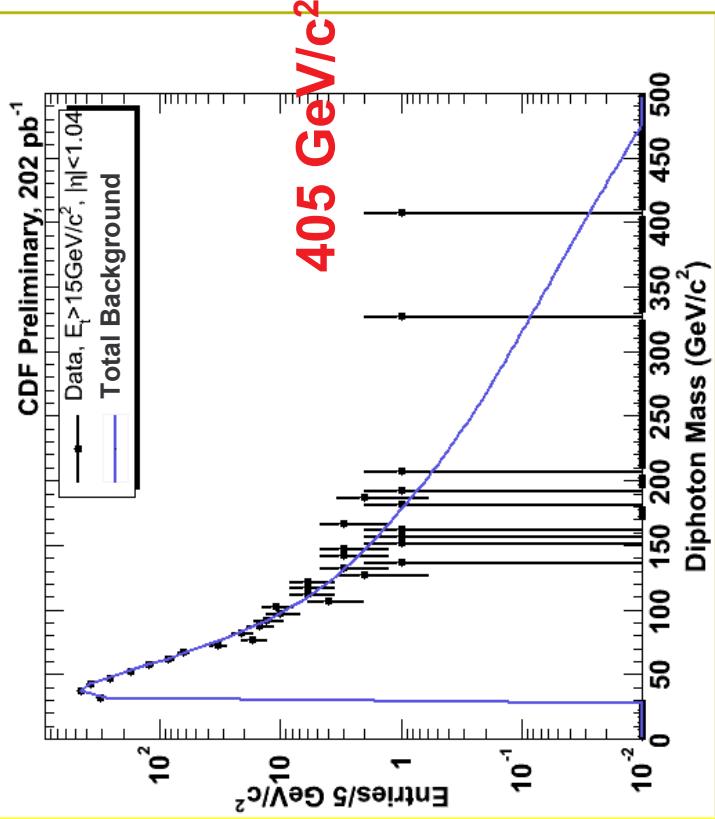


High Mass Diphotons



Backgrounds

- Standard Model diphoton production
- Fakes: γ -jet and jet-jet,
where jet fragments into a hard π^0



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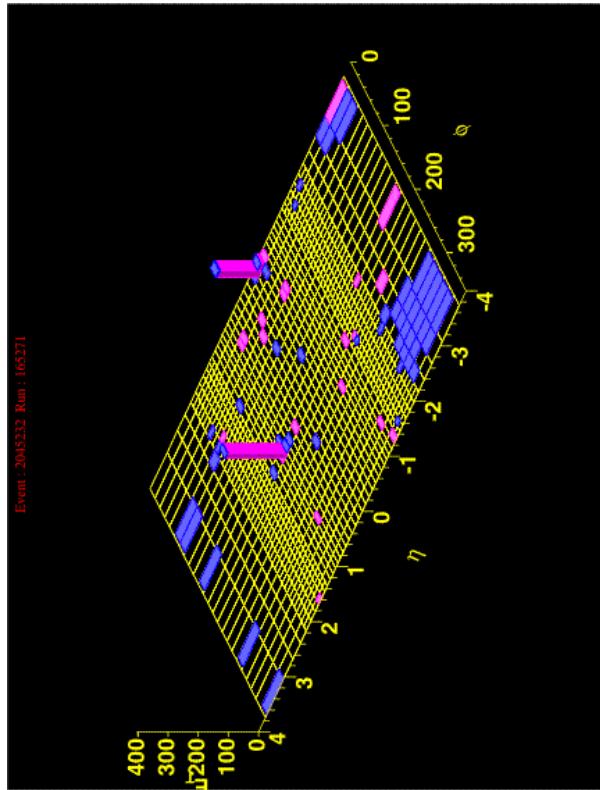
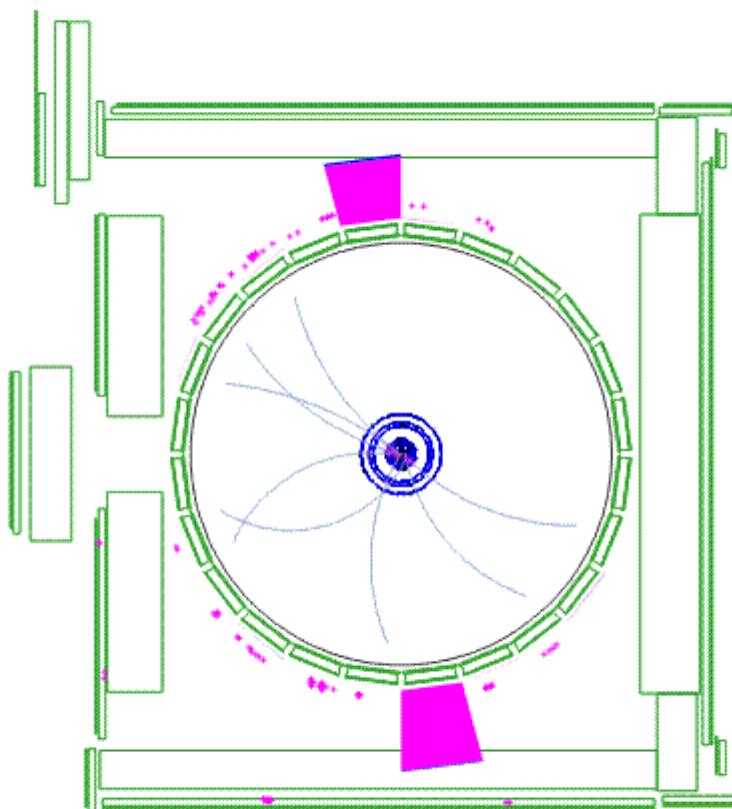
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$\gamma\gamma$ Highest Mass Event

Event : 2045232 Run : 165271



**Diphoton Mass = 405 GeV
Photon Et = 172, 175 GeV**

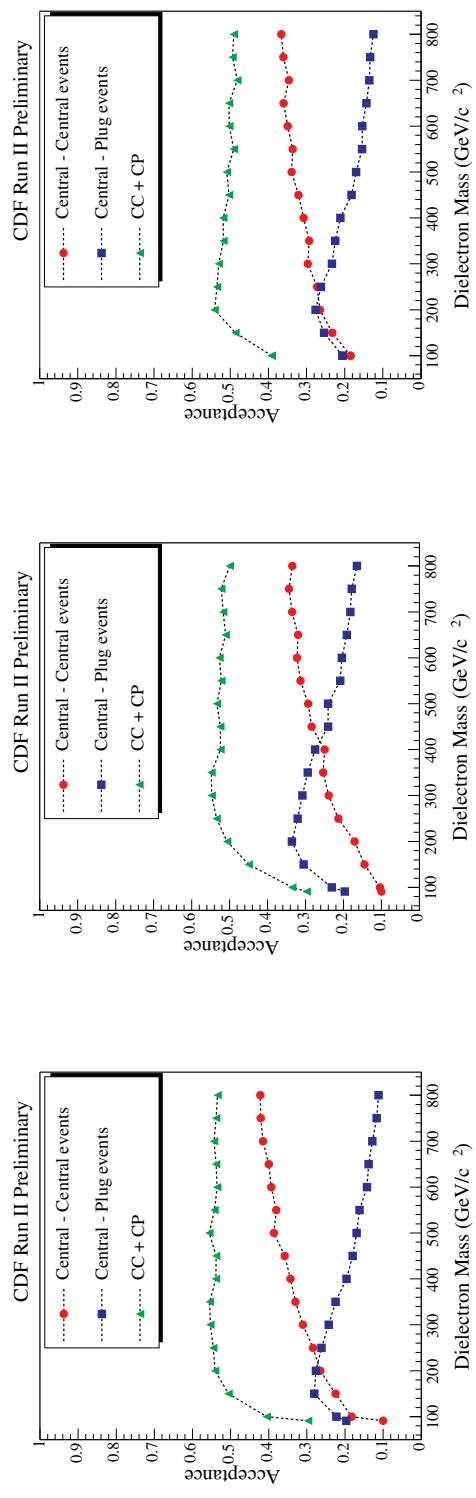
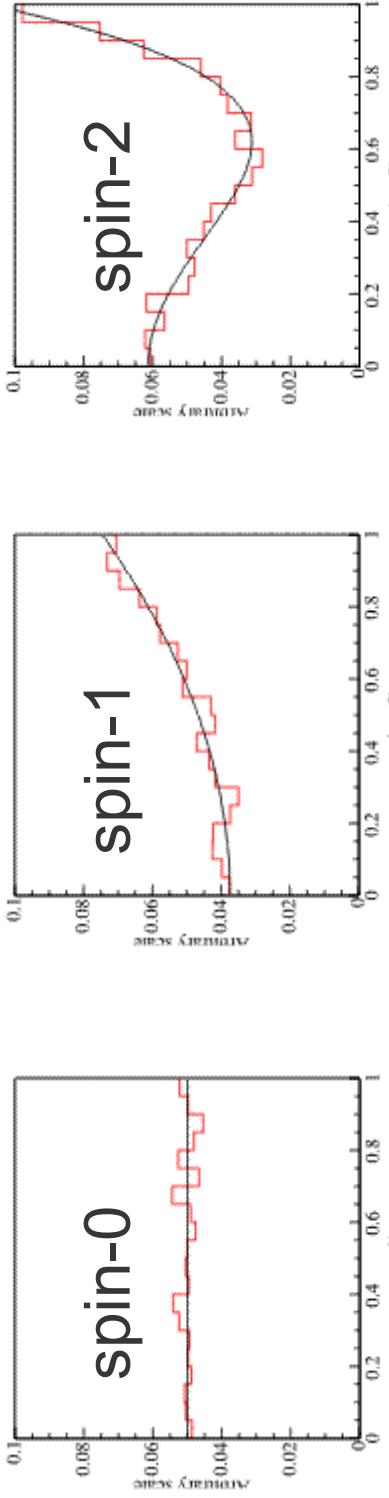
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Spin-dependent Acceptance

Angular distribution and therefore acceptance of decay products depends on the spin of the decaying particle.





New Physics Limits



95 % C.L. upper limits on $\sigma \cdot \text{BR}(G \rightarrow \gamma\gamma)$ are placed using $\pm 3\sigma$ search windows around M_G

95 % C.L. upper limits on $\sigma \cdot \text{BR}(X \rightarrow ll)$ for spin-0, 1,2 and lower limits on string scale are placed using binned likelihood method

$$L(\alpha/\eta) = \prod_i \frac{\mu_i^{n_i} e^{\mu_i}}{n_i!}$$

$$\begin{aligned} n_i &: \text{observed events} \\ \mu_i &= \alpha N_i^{\text{sig}} + N_i^{\text{bkg}} (\text{Resonant particles}) \\ \mu_i &= N_i^{\text{sig}}(\eta) + N_i^{\text{bkg}} (\text{LED spectrum}) \end{aligned}$$

Likelihoods are integrated to give the final limits, taking into account the signal and background systematic uncertainties

Sources of systematic uncertainties:

Luminosity (6%)

Acceptance (PDF, MC statistics..)

Energy/Momentum scale resolution

Selection Efficiencies

Background statistics and normalisation

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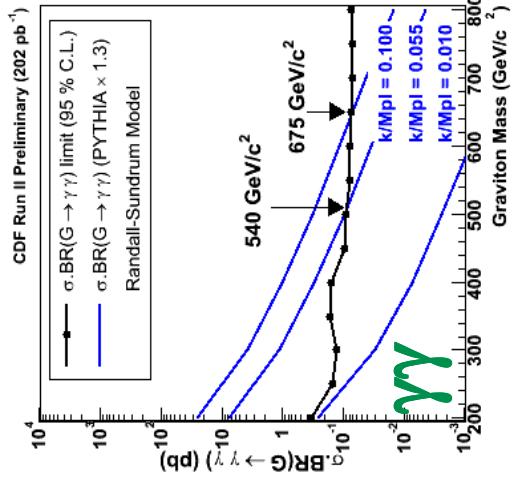
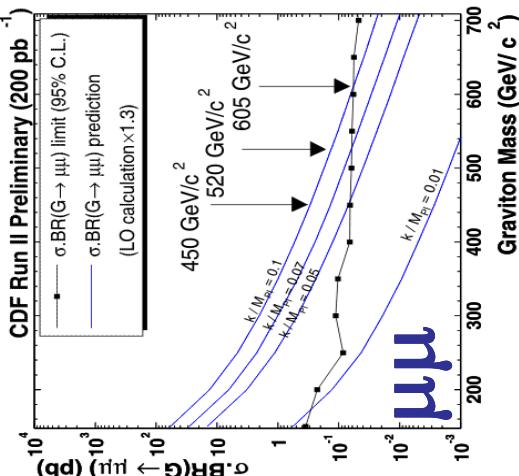
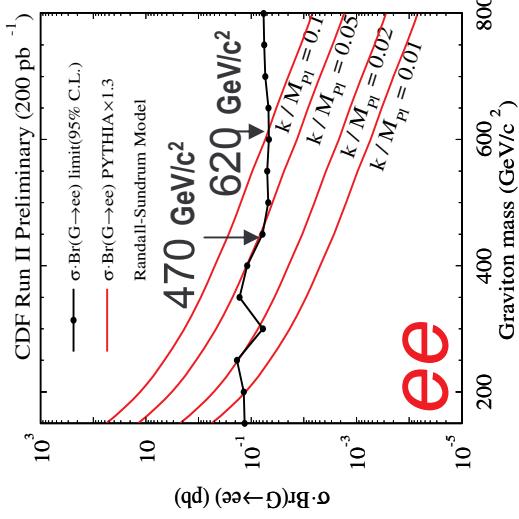
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$$N_{95\%} = \alpha_{95\%} N_{\text{sig}}$$

$$\sigma_{95\%} = \frac{N_{95\%}}{\varepsilon A \mathcal{L}}$$



Randall-Sundrum Graviton



ee has largest acceptance at low mass

γγ has largest acceptance at high mass

$$\text{BR}(\mathbf{G} \rightarrow \mathbf{\gamma\gamma}) = 2 * \text{BR}(\mathbf{G} \rightarrow \mathbf{ee})$$

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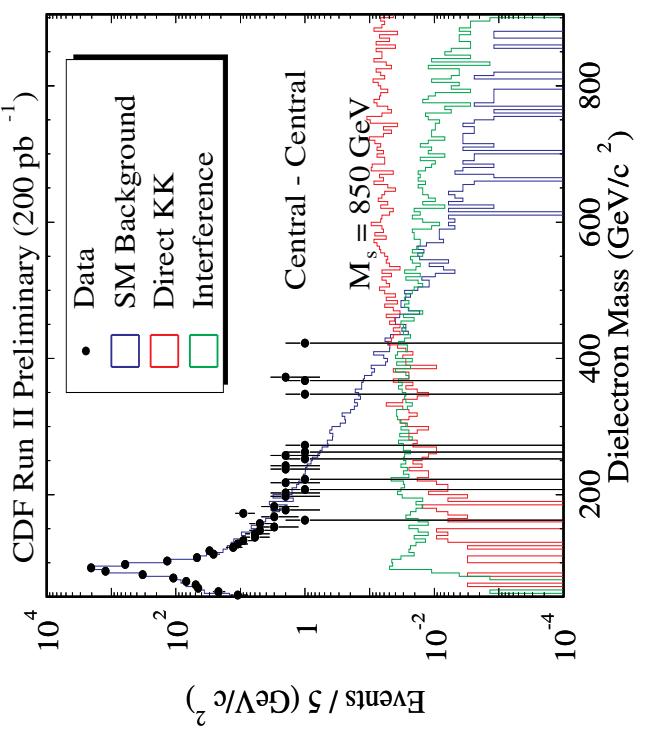
Large Extra Dimensions



Set a limit on the effective Planck scale (M_s^4) in ADD model

Parameterise the cross section in terms of $\eta = \lambda/M_s^4$ (* $\lambda = \pm 1$)

$$\sigma = \sigma_{\text{SM}} + \eta \sigma_{\text{INT}} + \eta^2 \sigma_{\text{KK}}$$



CDF Run II Preliminary (200 pb $^{-1}$)						
η_{95} ($10^{-12} \text{ GeV}^{-4}$)	* Hewett (GeV)	HLZ (GeV)			GRW (GeV)	
$\lambda < 0$	$\lambda > 0$	$\lambda < 0$	$\lambda > 0$	$n = 3$	$n = 4$	$n = 5$
1.05	1.18	987	959	1315	1105	999
				929	879	1105

CDF Run I: 780 768

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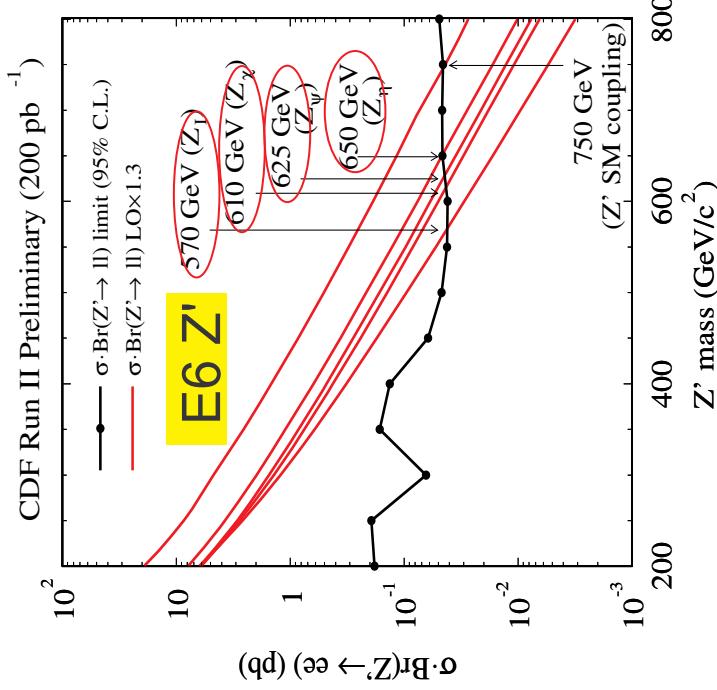
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Spin-1 Dilepton Limits

Z' bosons

Sequential Z': Reference model
with SM-like couplings to fermions
Free parameter $M(Z')$



CDF Run	L(pb⁻¹)	Mass Limit @ 95 %
Z' SM		
Run IA(92-93)	20	505
Run IB(94-94)	90	640
IIA (winter 04)	200	750
		735

Run I limits exceeded!

E6 Model Z': del Aguila et al., Nucl Phys B287 (87)
Unification of strong and EWK forces at
GUT

$$E6 \rightarrow (SO(10) \rightarrow SU(5) \times U(1)_\chi) \times U(1)_\psi$$

$$Z' = Z_\psi \sin \theta_{E6} + Z_\chi \cos \theta_{E6}$$

$$Z_\eta, Z_{l^\leftrightarrow} \theta_{E6} = \sin^{-1} \sqrt{3}/8, \sin^{-1} \sqrt{5}/8$$

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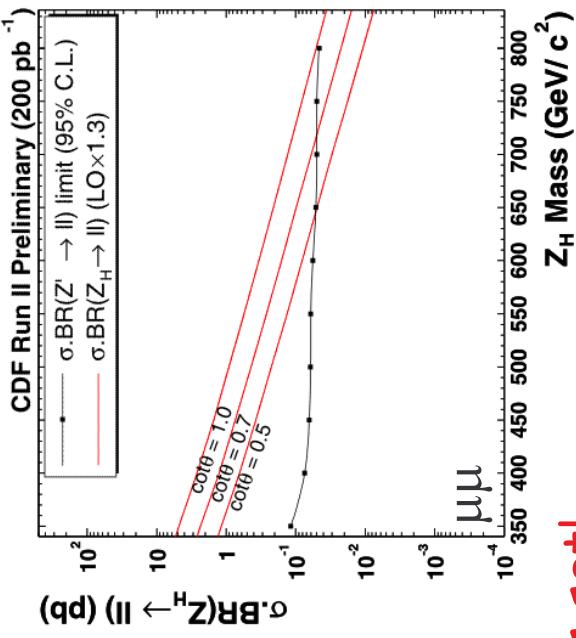
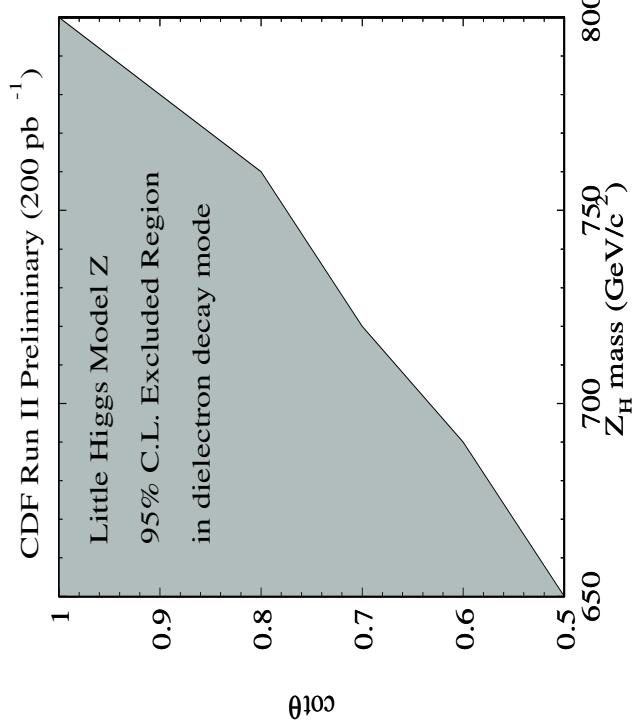


Spin-1 Dilepton Limits



Little Higgs Z'

Solve fine-tuning and hierarchy by
canceling divergences of Higgs mass
 $SU(2) Z_H$ coupling parameter $\cot\theta$



First limits set!

Littlest Higgs $Z_H (\rightarrow ee)$

$M(Z_H) > 800 \text{ GeV}/c^2$ for $\cot\theta = 1.0$

$M(Z_H) > 755 \text{ GeV}/c^2$ for $\cot\theta = 0.9$

Arkani-Hamed, Cohen, Georgi, Phys. Lett. B 513, 232, 2001
Han, Logan, McElrath, Wang, Phys. Rev. D 67, 095004, 2003

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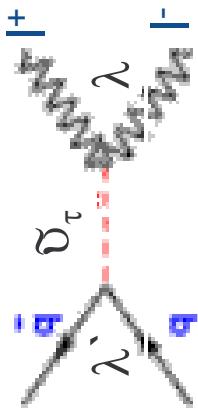
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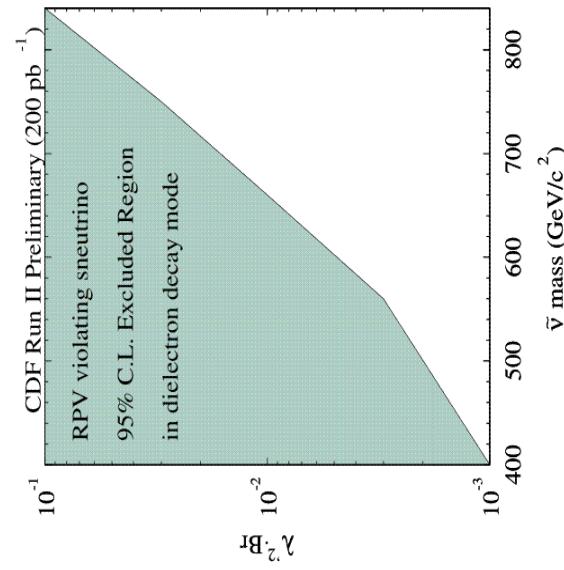
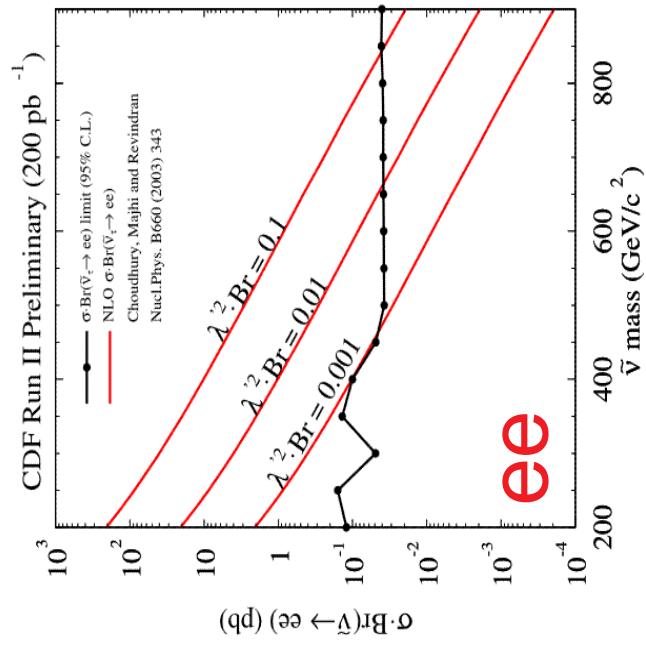
Spin-0 new physics limits



R_p sneutrino



$\lambda'^2 \cdot \text{Br}$	CC (GeV)	CP (GeV)	CC+CP (GeV)
0.1	830	710	840
0.01	650	550	660
0.001	400	340	400



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Summary and Conclusions

- Many searches for new physics at CDF are underway
 - Presented: preliminary results in high mass $e e + \mu \mu + \gamma\gamma$ (200 pb^{-1})
- ✓ Surpassed the sensitivity and results of Run I high mass dilepton searches
- ✓ Limits shown either exceed any published results of direct searches or are the first limits ever!
- Lots more CDF data to analyse
 - Combined results and publications are on the way

Many new exciting results from CDF
and more coming soon!

